

**Changes in Soil Nitrogen Mineralization and Nitrification at
Sawyer Mesa: 1992 to 1997**

Report Submitted in Partial Fulfillment of

P.O. #82036-7-0102

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Submitted January 30, 1998

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INTRODUCTION

The Nitrogen Cycle

Nitrogen is often the nutrient limiting production in conifer forests (Vitousek and Howarth 1991). To a large extent, the supply of nitrogen for plant growth in terrestrial ecosystems is determined by the rate at which organic-bound soil nitrogen is released in inorganic form; a process termed nitrogen mineralization (Fig. 1). The first inorganic form of nitrogen is ammonia (NH_3), which readily converts to ammonium (NH_4^+) in the soil solution. Ammonium (or ammonia) can be converted to nitrate (NO_3^-) through the two-step process of nitrification. Through the nitrification process, a portion of the ammonium-nitrogen can be lost to the atmosphere as nitrous oxide. Both ammonium and nitrate are assimilated by the soil microbial community and by higher plants. If demand for inorganic nitrogen by the microbial community is high, then concentrations of inorganic nitrogen within the soil may decline, which is termed 'immobilization.' Only when the demand by the microbial population is satisfied can concentrations of inorganic nitrogen increase within the soil, representing net mineralization.

Unlike ammonium, nitrate is negatively charged (an anion) and is mobile within the soil, which can lead to loss of nitrate from the terrestrial system to streams or ground water. Nitrate can be utilized by other microorganisms as a terminal electron acceptor, which results in the production of nitrous oxide or di-nitrogen (N_2) gas, through the process of denitrification. Di-nitrogen gas can return to the atmosphere, completing the cycle. Nitrous oxide also can escape to the atmosphere, where it can undergo reactions with other chemicals.

Both nitrate and ammonium are assimilated into plant and microbial biomass through growth. Plants and microorganisms can move nitrate towards themselves through diffusion, but they must grow or move to sources of ammonium which is more tightly bound to soil particles. Nitrogen assimilated by a portion of the microbial community contributes to plant growth through mycorrhizal associations (Fig. 1). A portion of the microbial and plant biomass is consumed by animals. Eventually, microorganisms, higher plants, animals and their associated wastes become part of the soil organic matter pool, a portion of which rapidly decomposes and undergoes the process of mineralization to continue the cycle. In general, monoterpenes alter rates of nitrogen cycling by slowing both the mineralization and nitrification processes (see White 1994 for a detailed review of the role of monoterpenes throughout the nitrogen cycle).

Nitrogen Mineralization and Site Productivity

Following field collection of soil samples, Vitousek et al. (1982) demonstrated that the nitrogen mineralization pattern shown by laboratory-incubated soils was nearly identical to the pattern shown in field studies. This pattern production of inorganic nitrogen in soils is represented in Figure 2. The process of nitrogen mineralization begins when ammonium is liberated from previously organic-bound forms of nitrogen. Often there is a slight time lag after the initial buildup of ammonium before nitrate is produced from the inorganic ammonium. If it is not immobilized in new microbial growth or taken up by plant roots, nitrate can move with soil moisture and percolate to lower soil horizons (shown by increase in lysimeter in Fig. 2) and possibly appear in streams.

Vitousek et al. (1982) also demonstrated that different nitrogen mineralization patterns were characteristic of ecosystems with differing productivity; highly productive systems sharing similar patterns and low productivity systems sharing different patterns. These patterns were a function of how fast the mineralization pattern occurred. In the least productive sites, the mineralization pattern was very slow and had only progressed to the point

of increased rates of ammonium production after incubation (Fig. 3). This pattern represents the initial portion of the mineralization pattern up to the dashed line B in Figure 2, at which point only an increase in ammonium occurs and no nitrate production. Sites with intermediate productivity had patterns that showed nearly the entire mineralization pattern compressed into the incubation period (Fig. 3). The mineralization pattern for the most productive sites was compressed to the point that only the final portion of the general pattern was demonstrated (Fig. 3), which represents the portion of the pattern shown in Figure 2 from the dashed line A. Other research has shown that these patterns vary with time, management practices, and most notably after fire (White 1996).

Fire and Productivity

Fire has played a significant role in nearly all western conifer forests. The reason fuels accumulate in these forests is actually very simple; production of organic matter (needles and wood) exceeds the rate of decomposition. If production continues to exceed decomposition, then fuels accumulate in the forest. Eventually, essential nutrients become sequestered in the fuels, which then limits production. Under these conditions, the amount of potentially mineralizable soil nitrogen is low, even though the amount of organic-bound nitrogen in and on the soil is very high. In the absence of fire, the system will reach a quasi-equilibrium amount of fuel with its rate of production equal to the rate of decomposition. However, the amount of fuel under these conditions is very high, which greatly increases the probability of fire and increases the resulting severity of any fire.

Fire affects nearly instantaneous decomposition through the combustion of organic matter, which releases a portion of the essential nutrients that were incorporated into the organic matter. These released nutrients are the basis of the immediate increase in potential site fertility, assuming other factors remain favorable. The combination of reduced organic matter and the increase in available nutrients act together to further increase the amount of

mineralizable soil nitrogen, which further increases the potential site fertility. However, since the fuels are often excessive under current conditions, essential nutrients can be lost either directly during the fire (volatilization of nitrogen) or through increased runoff and the associated erosion. If loss of nutrients occurs, then long-term potential production and the amount of mineralizable nitrogen can be decreased.

Fire used to occur frequently enough that fuels rarely accumulated to current levels. With high fire frequency (short return intervals) and low fuel loads, nutrients were sequestered in dead organic matter for relatively short periods before they were "freed" by decomposition or fire and became available for new plant production. Also, the low intensity fires would favor grasses and shrubs that have their reproduction portions at or below the ground surface which protected them from fire. Grasses would survive the low intensity fires and provide protection from erosion.

As part of the continuing effort to understand the effects of prescribed fire on the entire ecosystem, this study investigates the changes in soil nitrogen mineralization and nitrification in soils of Sawyer Mesa following fires set to provide a fire-break in effort to contain the Dome Fire in May of 1996. Soil samples collected and analyzed in 1992 as part of another study (White 1996) provide a relative "baseline" or pre-fire range in mineralization and nitrification. The purpose of the August 1996 collection (report submitted as 82036-6-0108) was to sample soils that demonstrated the range of observed fire severity (based upon tree scorch, canopy and forest floor consumption, and other soil characteristics) to describe the effects of this range in fire severity on soil nitrogen mineralization and nitrification. This report (submitted as 82036-7-102) provides the results from soil collections on August 29, 1997; a year after the post-burn collection of August 1996.

METHODS

Site Selection

The site is located on Sawyer Mesa at an approximate elevation of 2670 m. Fire records obtained from trees near the research site (Touchan, Allen, and Swetnam 1996) indicate that wide-spread fires had not occurred at that site since 1893. The soils are derived from volcanic tuft parent material (Smith et al. 1970). The samples were collected from areas that were thought to include the range of fire severity observed at that site, but did not include areas that had no evidence of burning. Soil collections avoided all surface-lying lithics and surface manifestations of past habitation, if present. Eight samples were collected on August 29, 1997, corresponding to the eight samples collected in August of 1996, whereas only four were collected in 1992 before the burn. Samples included the 0- to 10-cm depth mineral soil horizon.

Analytical Methods

Methods detailed in White (1991a) were used to analyze all samples. All mineral soil samples were analyzed for nitrogen mineralization/nitrification potentials by aerobic incubation and subsequent extraction with KCl. The KCl extracts were analyzed for ammonium and nitrate with a Technicon AutoAnalyzer.

RESULTS

Soils collected in 1992 showed a fairly typical range in mineralization patterns. Most soils produced little or no nitrate and relatively small amounts of ammonium during the 70-day incubation period (see 82036-6-0108). The highest amount of nitrate was produced in a soil that had a mixture of overstory trees, including aspen which is known to produce more nitrate than most conifer soils (Vitousek et al. 1982). The average concentrations of ammonium and nitrate (with standard error bars) produced during the 70-day incubation are displayed in Fig. 4. After the 1996 fire, nitrate was produced in all soils in relatively high amounts and net nitrogen mineralization was 2 to 8 times higher than the pre-burn soils (Fig. 5). The lowest amount of mineralizable nitrogen in the post-burn soil was about equal to the highest amount in

the pre-burn soils. However, only three of the eight post-burn soils showed a lag in nitrification (no nitrate production until later during incubation), whereas all the pre-burn samples showed a lag in nitrification. One year later (the August 1997 collection, Fig. 6), the nitrogen mineralization pattern was distinctly different. Soil nitrate was significantly ($P < 0.004$) higher at the beginning of the incubation than nitrate in soils from the previous collections. The nitrogen mineralization pattern more closely resembles that of high productivity sites with immediately increasing nitrate concentrations and low, nearly constant concentrations of ammonium (similar to "A" in Fig. 3).

DISCUSSION

The relatively low amounts of mineralizable nitrogen in the soils of Sawyer Mesa before the fire (Fig. 4) are fairly typical of conifer stands of this region (White 1996). This pattern is also typical of low productive sites, represented by "C" of Fig. 3.

The fire on Sawyer Mesa included patches with no detectable fire (scattered grass or bare areas, not sampled after fire), patches where the organic layer (forest floor) overlying the mineral soil was only partially burned and most of the overstory trees were unscorched, other patches with the overstory mostly scorched and only portions of the forest floor remaining, and "hot spots" where the overstory was completely scorched or burned and little more than ash remaining from the forest floor. At least one soil sample was taken from each of the situations described above, for the explicit purpose of describing the variation in burn responses. According to the National Park Service classification (Kay Beley, personal communication), most of the area was identified as having light burn with moderate (possible burn classes included *light*, *low*, *moderate*, and *high*) the most severe classification on Sawyer Mesa. Relative to pre-burn soils, inorganic nitrogen was expected to be higher in the least severe of the burned spots. Areas with the hottest burn might have experienced significant loss of

inorganic nitrogen through volatilization, but this did not appear to occur. In fact, the soils beneath the most severe burn areas (in the moderate-burn class) still had high concentrations of organic matter and mineralizable nitrogen.

The high concentrations of ammonium in the soils after the fire (Fig. 5) indicate that potential site fertility was increased after the fire. The high rate of nitrate production indicates that longer-term site production may be higher after the fire. One year later, the absolute concentrations of ammonium and nitrate had declined (Fig. 6), but the overall mineralization pattern was similar to that of forests with high productivity (see "A" in Fig. 3). Although the total amount of inorganic nitrogen was significantly lower ($P < 0.02$) at the end of the 70-d incubation in the '97 collection relative to the '96 collection (32.7 and 67.5, respectively), the mineralization pattern shows that most soil ammonium can be rapidly transformed to nitrate, which then can migrate within the soil to areas of high consumption (i.e.; plant roots). The overall decline in total inorganic nitrogen could result from plant uptake and/or erosional and leaching losses.

CONCLUSIONS

Burning of Sawyer Mesa to control the Dome Fire immediately increased production of mineralizable nitrogen and thus potential site fertility. Rapid rates of nitrification persisted in the soils a year later, but the total amount of inorganic nitrogen was about half that of the soils in Aug. 1996. The mineralization pattern in Aug. 1997 was similar to high productivity forests. Research within the region suggest this change in mineralization patterns should persist for a number of years.

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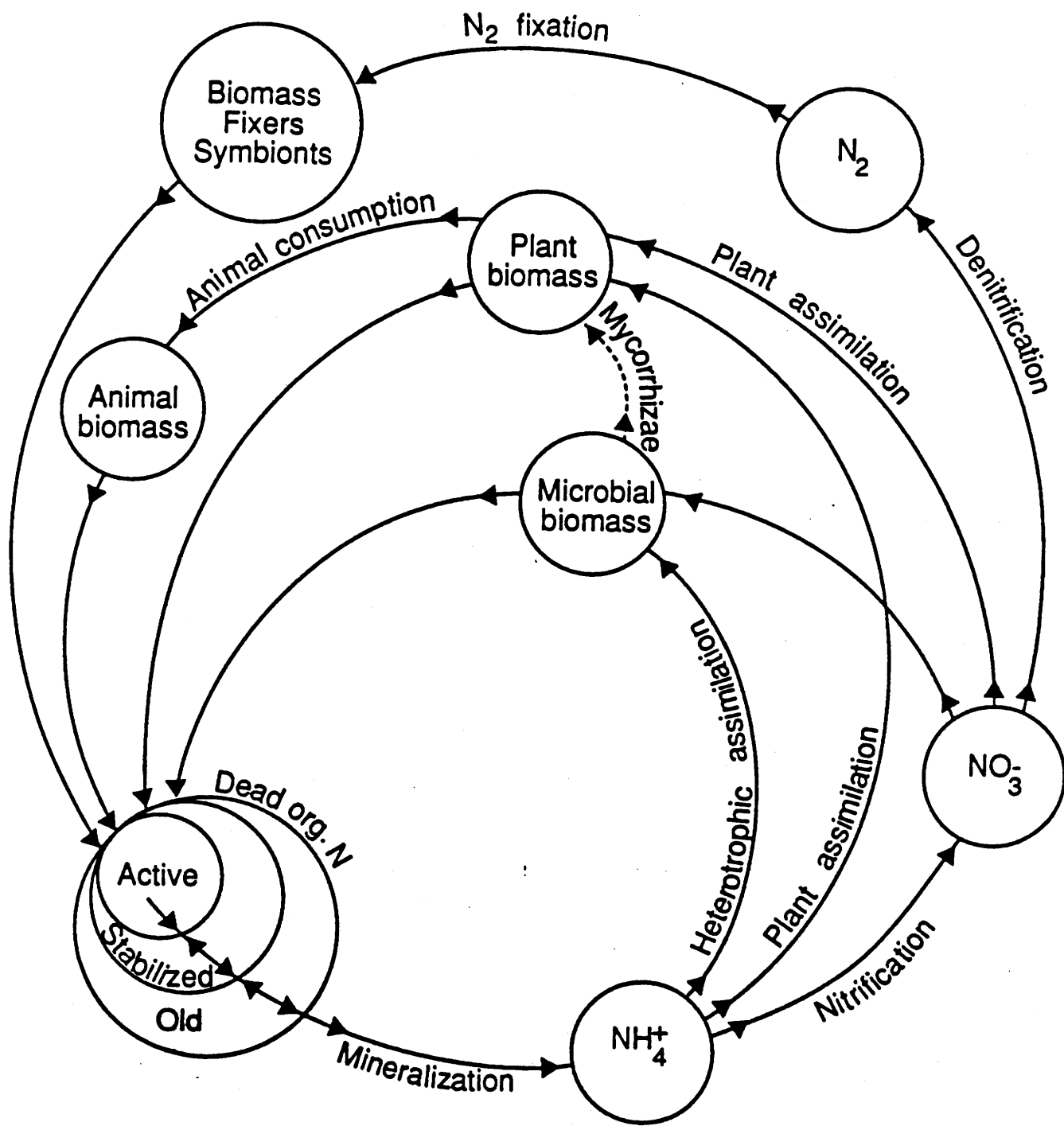


Figure 1

Nitrogen Mineralization Pattern

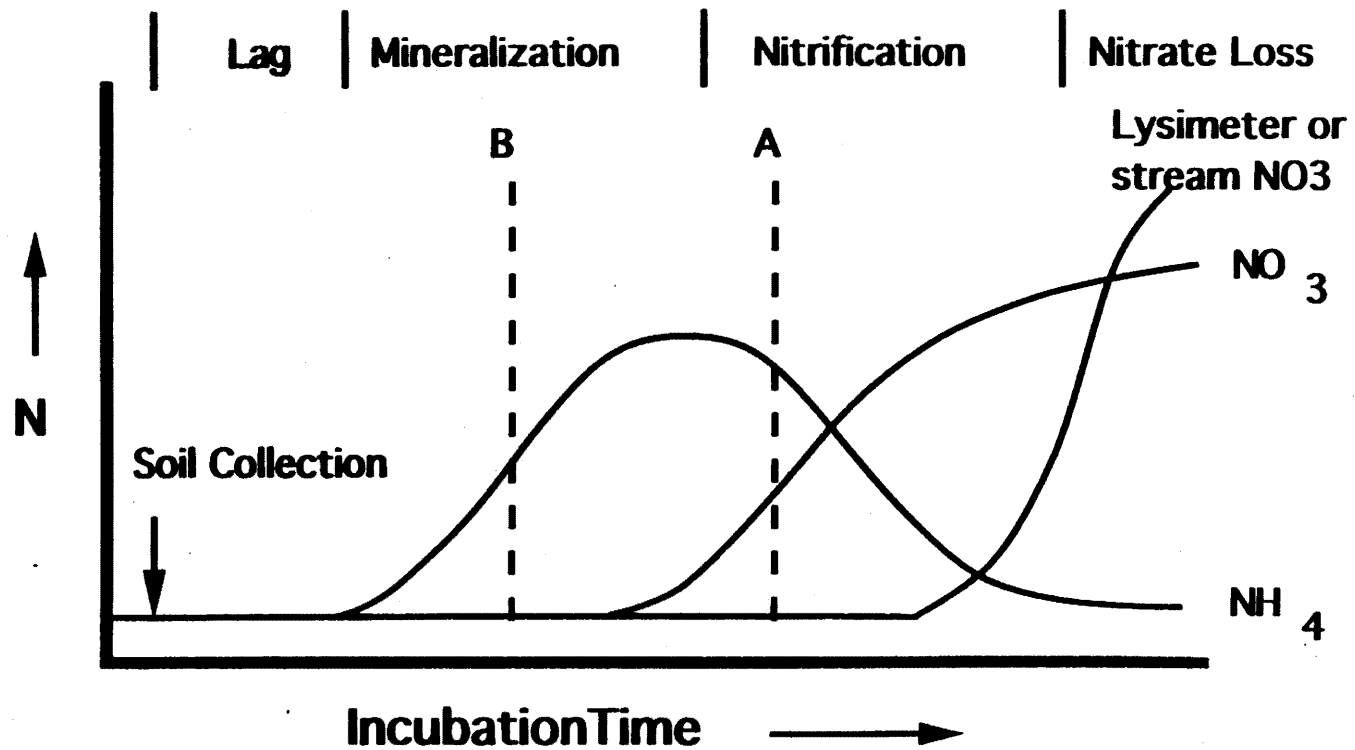


Figure 2

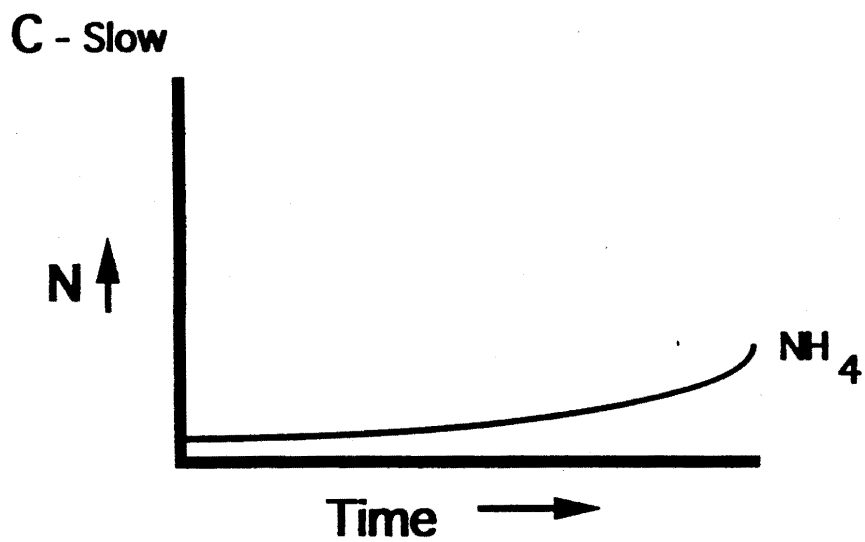
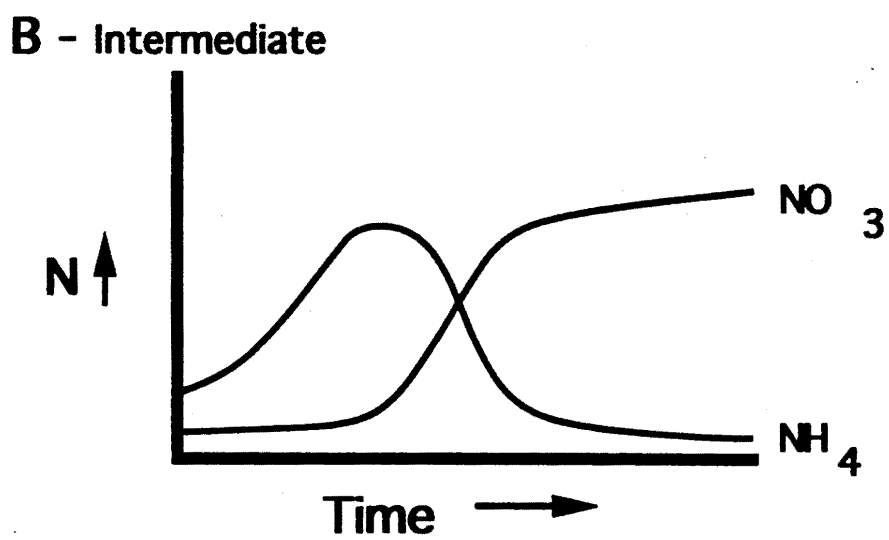
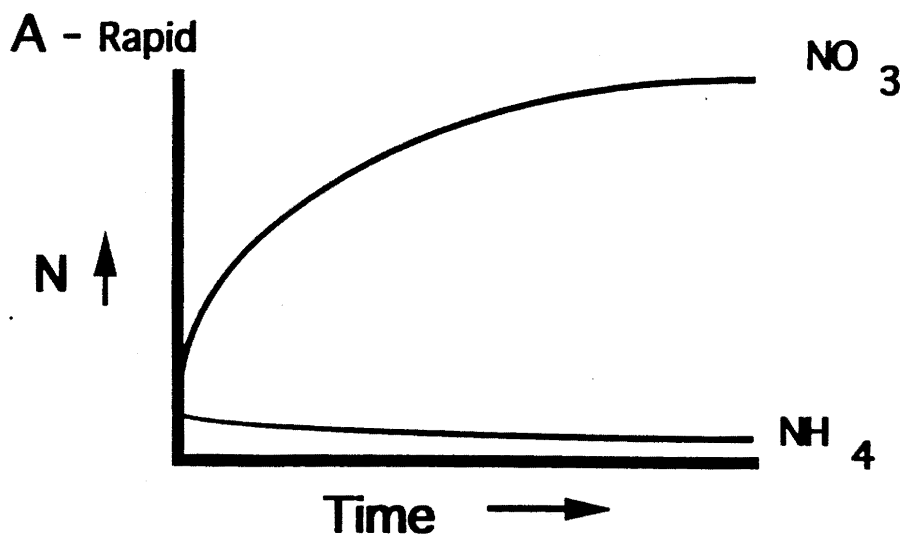


Figure 3

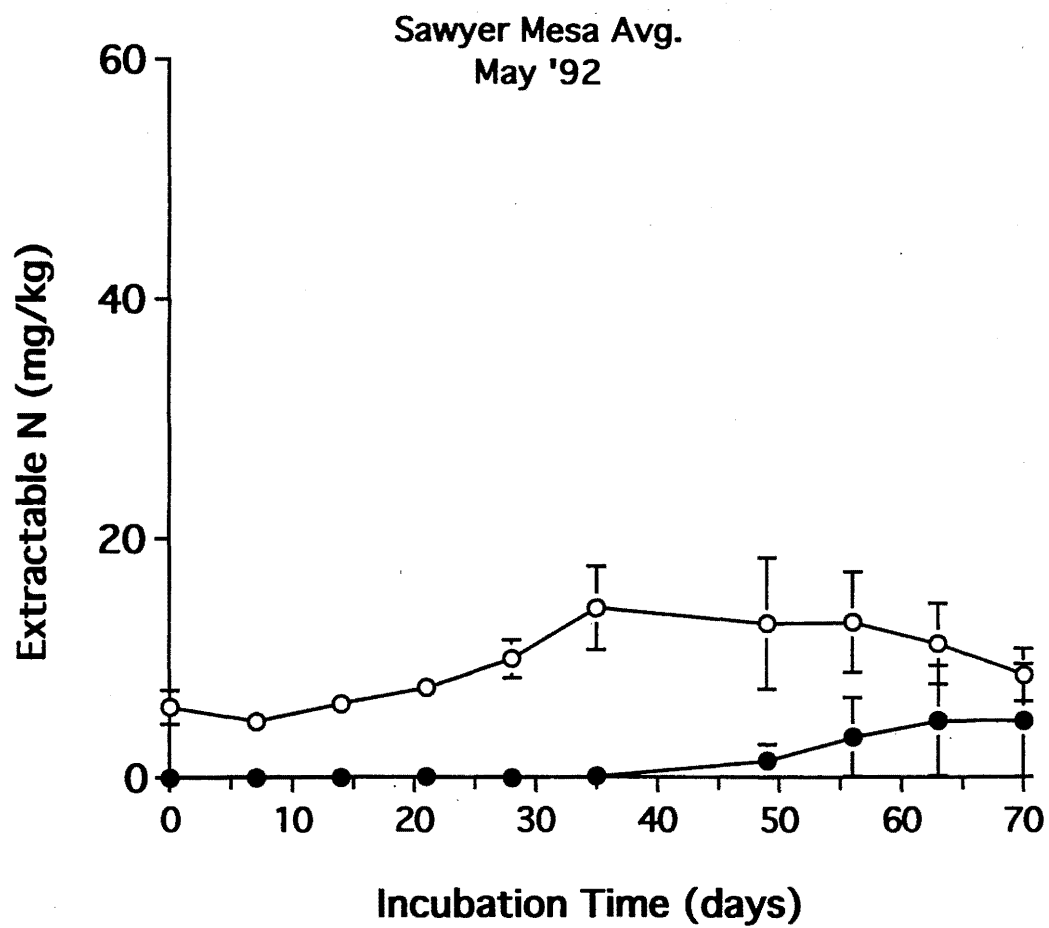


Figure 4.

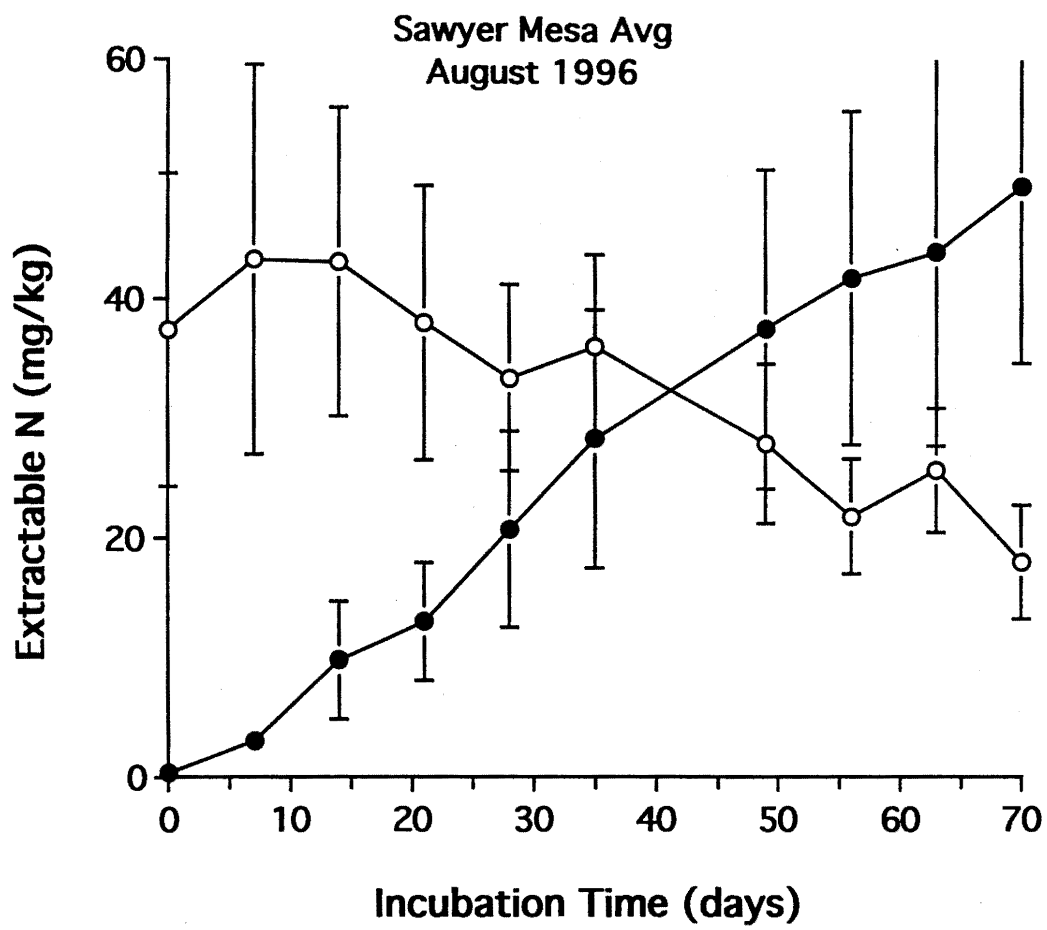


Figure 5.

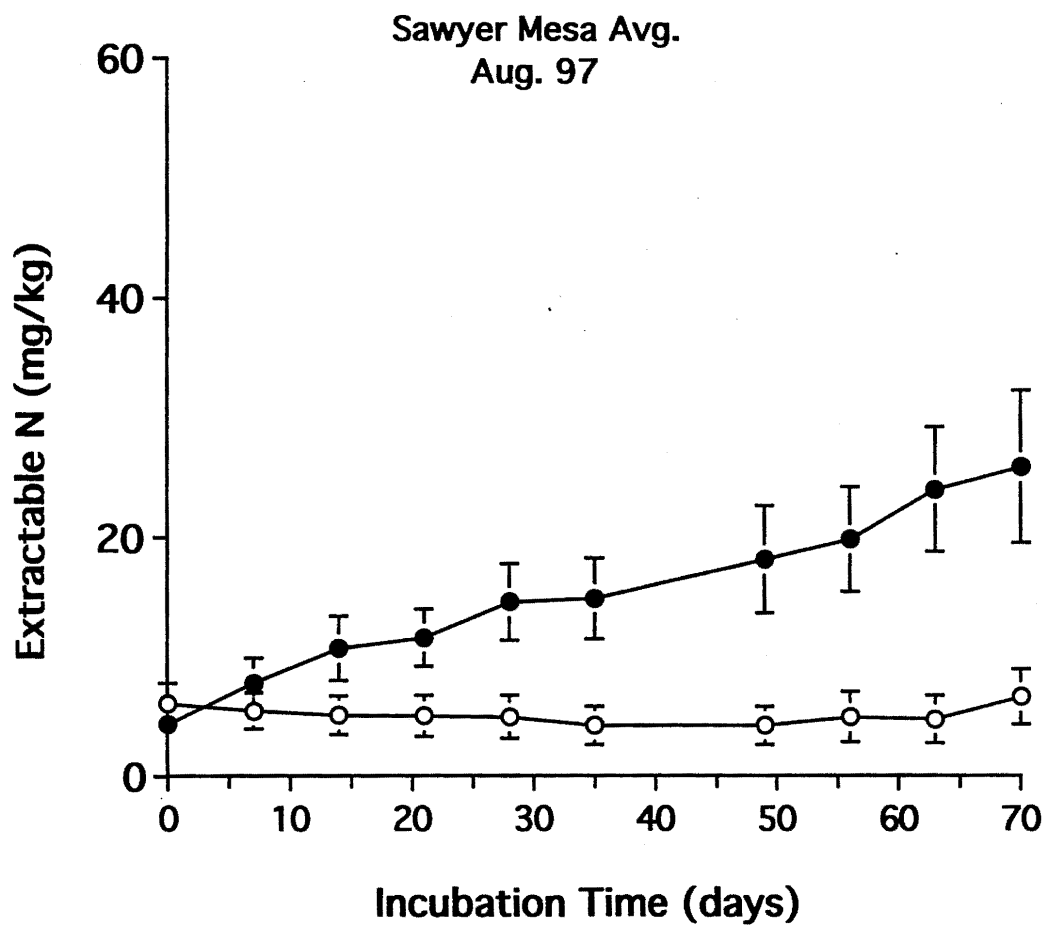


Figure 6.